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I am knowledgeable in the English language and in the language in which the below identified application was filed, and that I believe the English translation of

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is a true and complete translation.

All statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Passivation of deep isolating separating trenches by sunk covering layers

The present invention relates to a method for processing or treating of semiconductor wafers including insulating isolation trenches for forming integrated semiconductor circuits, in particular directed at a reduction of a bending of the process wafer, thereby avoiding the creation of interfering crystal defects during the further process flow. The product by process without steps within the cap layer is also claimed.

For the integration of low voltage logic elements and high voltage power elements into the same silicon circuitry it is necessary to insulate chip areas from each other that have different potentials. One approach in this respect is the so-called dielectric trench isolation. In this case a first vertically acting insulation is formed between the device and the substrate by a buried insulating layer (typically comprised of silicon dioxide: SiO_2 , in principle, any other insulating layers may be used). A further laterally acting (vertical) insulation is established by etching a trench down to the buried insulating layer of an SOI wafer and a subsequent refilling of this deep trench with insulating layers (insulating isolation trench). In this case only a portion or lateral section of the etched trench may be filled with an insulating material, the remaining fill process may then be performed on the basis of at least one conductive fill layer (e.g., polysilicon).

By means of so-called planarization steps, for instance appropriate etch processes or chemical mechanical polishing processes a planarization of the surface may be accomplished.

The representative prior art is found, for example, in EP-A 1 184 902 and EP-A 1 220 312. The process step for forming the insulating isolation trench is in the middle of the process flow, that is, further high temperature process steps follow. During the subsequent further manufacturing process also oxidation steps are required for thermally forming oxide layers. Thereby, an oxidation of the vertical side walls within the insulating isolation trench is induced. With the usual employment of polysilicon as fill layer there is additionally an oxidation of the polysilicon at the surface and also inside the filled insulating isolation trench.

Due the higher specific volume of the created silicon dioxide compared to the polysilicon significant compressive stress is generated in portions near the surface of the filled isolation trenches, thereby inducing an expansion of the isolation trenches and a bending of the silicon wafer as well as generation of crystalline defects in the adjacent single crystalline silicon areas, respectively. The crystalline defects impair the characteristics of the devices and result in increased defective goods, respectively. For this reason the trench areas are covered by an oxygen impermeable layer or a corresponding layer system, as is known from **US-A 5 933 746**. Such cap layers are also described in **US-A 5 581 110**, **US-A 2002/0025654**, **JP-A 2000-183156** and **JP-A 63-003429**. A disadvantage of such cap layers designed in a known manner is that these layers extend above the planar surface, which entails disadvantages in the further manufacturing process. The layers form a step, which may negatively affect the formation of conductive lines extending across the step, for instance due to a reduced thickness at the line edges. Moreover, the cap layers are defined by an additional photolithographic process and are subsequently etched, that is, a photo mask has to be formed and deposited on the wafer, and there is the risk of a lateral misalignment of the photo mask.

It is an object of the present invention to provide a technique for forming insulation trenches in SOI wafers, while avoiding the disadvantages of the cap layers of the insulation trenches protruding from the planar semiconductor surface and facilitating the process flow of a photolithography process. Furthermore, yield increase and reliability enhancement of integrated circuits having, in addition to low voltage logic elements also high voltage power elements, are to be taken into consideration and to be met.

The inventive solution proposes a method for forming a process wafer, wherein the formation is the treatment or the processing of an available SOI wafer, by forming specifically configured isolation trenches (claims 1, 27, 31). This enables an enhanced dielectric isolation of chip areas, which are or will be provided in the active semiconductor layer. One of the chip areas may be at a first potential and the other chip area may be at a different potential, wherein these potentials may exhibit a very high difference as a voltage or potential difference, so that low voltage logic elements may be provided in one area and high voltage power elements may be provided in a neighbouring different area. Both types of "elements" are referred to as devices in the context of semiconductor technology and may not further be explained, since these elements may be formed according to well-established conventional techniques.

The dielectric isolation is achieved by insulating regions comprising at least one trench, and preferably plurality of trenches, which isolate the chip areas from each other.

5 Starting from a planar surface, from which the trenches extend downward, the trenches extend to a horizontally located buried insulating layer that is provided in SOI wafers.

10 The isolation trenches comprise at least one oxidizing material, for example, a polysilicon used for filling, which oxidizes in an oxygen containing atmosphere at temperatures above room temperature. The oxygen containing atmosphere is prevented from entering the (insulating) areas of the trench filling by a cap sunk into the upper area of the trench according to the present invention. Despite the cap layer the surface may be designed in a planar manner, that is, above the trench and aside the trench laterally offset therefrom in regions extending in at least edge areas of the trench, and even across the entire surface of the active semiconductor layer of the SOI wafer.

15 When hereby „main process steps“ are referred to during the manufacturing process, this is to be understood such that these process steps are emphasized in view of the object and the invention described and claimed herein; however, other processes, such as the integration and the processing of the low voltage elements and the high voltage elements or the etching of the trench structure are not to be excluded.

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The following main processes are provided, when the processing or the treatment of the semiconductor wafer is demonstrated in a time sequence of the total process flow.

25 Hereby, only one isolation trench is illustrated, although a plurality of such isolation trenches is provided on a processes wafer, wherein the plurality of isolation trenches electrically isolate high voltage elements and low voltage elements from each other. At least one of the trenches is the subject of the description and the claims, which may readily be extended to a plurality of such trenches.

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At least one of the existing isolation trenches is provided with insulation layers, which extend as vertical insulation layers into the depth of the trench, thereby reaching to the horizontal (buried) insulation layer. At the same time a horizontal insulation layer is formed on the top of the active semiconductor layer. The fill material has a deep notch or indentation, which is still located above a height level of the horizontal insulation layer. Thus, also a horizontal section of the deposited fill material, which not only fills the isolation trench but is also located above the horizontal insulation layer to form a fill material layer in this area. Insofar, it may be said more generally that “insulation layers

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are formed", which comprise horizontal and vertical portions or area sections. Both type of portions are covered by filling the at least one isolation trench.

In a further process step the fill material layer is planarized. This is a "first planarization".
5 Subsequently, a controlled back removal, in particular a defined back etching (back etch) is performed, which concerns the fill material in the interior of the trench, that is, below the planar surface, which is formed by the horizontal portion of the insulation layer. This removal into the trench provides for a reduction of the fill height of the trench including the oxidation sensitive fill material. This removal process is also referred to as
10 an over-removal, which extends to "a first defined depth" of the trench, in any case to far above the trench bottom and only in the upper portion, preferably above half of the trench depth or even far above this half depth (claims 21, 22). The method is thus very appropriate for particularly deep trenches (claims 23, 24 and 25), which may extend through the entire active semiconductor layer to the buried insulation layer, not only into
15 a certain portion of the semiconductor substrate. In this way high voltage and low voltage at different chip regions may reliably isolated, while avoiding oxidation influences at the surface of the trench, when this trench is filled with an oxidation sensitive material. In order to incorporate in the trench or lower the cap or cover layer provided for an oxidation barrier a removal of a portion of the insulation layers and a
20 further removal of a further portion of the fill material are performed.

Here, the respective vertical portions of the layers are involved and meant in order to obtain a substantially identical height level of these layer in the isolation trench or achieve the same by the additional removal process. The horizontal insulation layers are also removed so that a surface of the active semiconductor layer is exposed. This over-removal, in particular, a defined over-removal, provides a volume in the trench at the upper trench edge for accommodating a cap layer that is now to be incorporated, which extends above the level of the planar surface after deposition in the form of a layer or layer system, however, the cap layer extends downwardly to the substantially equal height level of the trench, supported by the remaining vertical layers in the trench, a fill layer and a residual insulation layer at both sides.
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After the application of this cap layer, which is initially provided in a greater extent than required in a later stage, a further planarization process is performed. This further planarization reduces the cap, representing a functional description of a layer or a layer system, by evenly removing material using for instance a mechanical chemical polishing process or a further resist planarization process in order to again expose the surface of the active semiconductor layer, cover the trench in the upward direction in an oxide
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inhibiting manner, in particular in the area of the trench and the near the trench such that steps are avoided, which would complicate the formation of horizontal conductive lines.

5 All of the described process steps are performed without an additional photolithography step; the only photo mask required is used for forming the trenches, in this case, the at least one described trench. In addition to avoiding further photo masks there is also no requirement for aligning these further photolithography processes to each other, so that lateral misalignments of photo masks are avoided. Oxidations may no longer occur in
10 the upper portion of the trench, thermal stress is avoided (claim 6), or is at least significantly reduced. Further high temperature processes may follow the formation of the trench structure without a risk for generating thermal stress that would result from occurring oxidation processes in the upper trench portion. The process performance of the wafer is enhanced so that also yield may be increased.

15 If a plurality of layers are used as a layer system at least one of the plurality of layers may be formed in a special way. In this case, on the one hand, the getter capability of ions may be taken into consideration, as well as a certain coefficient of thermal expansion. The lowered cap layer of the isolation trench enables the avoidance of a
20 mutual negative influence of circuit portions and trench portions, such as the migration of ions. A layer component may also be used for adjusting the coefficient of thermal expansion of the total system (claim 2, claim 4).

25 Particularly advantageous is the usage of silicon nitride as an oxygen impermeable cap layer (claim 3).

The product or intermediate product of the processed wafer or process wafer in the sense of an at least partially processed SOI wafer is the subject-matter of claim 26. In this claim the structural features of the process wafer defined by claim 1 are claimed as
30 a structure. The skilled person is able to determine the structure of the wafer treated or processed according to the method of claim 1 so that a relation to the manufacturing product of a manufacturing or production method is possible.

Claim 28 describes in a clear language the structural features without a „process“.

35 An alternative method defines in a concise manner the process flow (claim 31), respective embodiments are defined in the respective dependent claims.

The continuous planar surface relates to the cap layer and the neighbouring areas, which are chip regions provided for low voltage and high voltage (claim 7). The plane is formed in a planar manner and does not form steps. The cap layer lowered into the trench also forms a laterally acting electrical insulation that extends across the entire trench width, while vertical insulation layers at the trench walls in the upper area of this cap layer are not involved (claim 13). The latter insulations are formed by, for instance, thermal oxidation and are completely removed with regards to the horizontal portions in a later stage, with regards to the vertical portion is removed only to a certain extension in order to provide the space for recessed cap layer (claim 8, claim 10). The back removal is defined and thus relates to a smaller piece of the vertical portions in the trench only (claim 12). Nevertheless the removal on the trench is performed over the entire trench width between the trench walls, which are defined by the neighbouring portions of the active semiconductor layer (claim 10).

It is to be appreciated that the cap layer is dielectrically insulating. It is also to noted that the cap layer is an oxide barrier for the fill material provided below the cap layer. This cap layer is formed without a mask (claim 12).

A dielectric insulation by means of trenches is also described in **US-A 2003/0013272** (Hong) or in **US-A 2003/0235975** (Tran). However, in these cases the trenches or their depths terminates in the homogenous semiconductor material, and at the end phase of the manufacturing process a continuous planar surface corresponding to the surface level of the semiconductor wafer is typically not achieved. In the former document the free surface maintains covered by a double layer and is not planar. In the latter document the trenches are used for the isolation of differently doped regions. These regions are not provided for different potentials, such as high voltage and low voltage, that is, for accommodating power elements and logic elements, so that the trenches in the prior art may have to withstand, with respect to dimensions and design, very reduced potential differences.

The invention will be explained and supplemented by referring to embodiments including two semiconductor wafers and by using the accompanying drawings.

5 **Figure 1** illustrates the prior art.

Figure 2 illustrates an example of a covered trench according to the present invention.

10 **Figure 3a to**

Figure 3f are process stages of main process steps for forming an isolation trench having a planar end face of the oxygen impermeable cap layer, as is for instance shown in Figure 2.

15 **Figure 4** is a trench structure according to a scale.

20 **Figure 1** illustrates an isolation trench according to a vertical section of an SOI wafer, wherein cap or cover layers 8, 9 are provided. The cap layers 8 and 9 are located on the planar surface F' of the active semiconductor layer 3, thereby producing a disadvantageous step at Fx. The insulating trench T separates two regions of different potentials, wherein these regions 6, 7 are depicted while the different potentials are generated during operation of a completely processed wafer separates into individual devices having the semiconductor associated therewith. In addition to the trench T the buried insulating layer 2 and the two insulating layers 4a, 4b, commonly referred to as "insulating layers 4" also provide for the dielectric insulation. The planar surface F' of the active semiconductor layer has at least two lateral steps according to the covered embodiment of Figure 1, thereby inducing the previously described drawback.

25 The SOI embodiment of Figure 1 initially includes a carrier layer 1, an insulating layer 2 located thereon and the active semiconductor layer 3, which in this stage is already structured by the trench T and its vertical insulating layers 4a, 4b and a fill layer 5.

30 Nevertheless, in the following this layer 3 shall be referred to as active semiconductor layer, including the buried insulating layer 2, to which extend the two vertical insulating layers 4a, 4b of the insulating layer 4.

35 In **Figure 2** there is shown an example of the novel trench structure. Here the cap layer 9 is provided such that it forms an even plane in combination with the planar surface F of the semiconductor wafer, i.e., there is no longer a step or a notch. In particular, at the trench and adjacent thereto no steps are provided, since the cap layer 9 is sunk into the trench. Like reference numerals identify like elements, wherein in the following a

manufacturing sequence is described, with which the structure of Figure 2 may be formed.

In use the chip region 6 and the other chip region 7 are provided with low voltage and high voltage elements, respectively, which are formed after the herein described formation of the trench structure by processes for semiconductor devices that are not specifically explained herein and that are generally known. It may only be appreciated that a first potential (P1) is assigned to the chip region 6 and a second potential (P2) is assigned to the chip region 7. These chip regions are portions of the active semiconductor layer 3 that is preferably made of silicon.

It should be noted with respect to the former stepped trench structure shown in Figure 1 that the arrangement of the trench area T (T indicates a „trench“) and of the two potential areas P1 (region 6) and P2 (region 7) are also determined, insofar there is no difference. It is merely to be noted that the stepped cap of the prior art is made of an oxide layer 8, which covers the trench 5, 4a, 4b and the fill layers contained therein, and is additionally covered by a cap 9', which additionally covers the insulated isolation trench, such as Si_3N_4 .

Using Figures 3a to 3f a preferred method will briefly be illustrated. The isolation trench of Figure 3a, here indicated as 5a and created by etching to the buried insulating layer 2, is provided with insulating layers 4, for instance by thermal oxidation. Thereby, the trench structure of Figure 3b is obtained. After filling the trench 5a', for instance using polysilicon 5, above the planar surface 4c, thereby forming a structure according to Figure 3c, the fill material 5 is planarized and subsequently etched back in a defined manner as shown in Figure 3d.

Thereafter a further etch back process of the insulating layers 4 including a defined over etch is performed so that the two layers 4 and 5 have substantially the same level, as is shown in Figure 3e. Next, the cap layer 9 is formed and subsequently planarized, as is shown in Figure 3f. This may be accomplished by a chemical mechanical polish process or by a resist planarization process, which are well-known and thus are not illustrated.

The method illustrated does not require any further photolithographic masks for forming the cap of the isolation trench, except for the mask for the isolation trench 5a.

The insulating isolation trench may also be covered such that a mutual adverse influence of the circuit areas and the interior of the trench is avoided in the further

technological process flow, for instance the migration of ions. During the formation of the layer system having respective characteristics a layer component may also be used for adjusting the coefficient of expansion of the total system.

5 In detail on the one hand the method up to now will be explained and completed. The detailed description may, on the other hand, be considered as a further embodiment of alternative methods that are capable for producing the product of Figure 2, whose real size and shape is demonstrated by Figure 4.

10 The trench structure, from which one trench is illustrated in cross-sectional view and which is formed by means of a first mask, is not explicitly shown as a mask, the result of the method is shown only. The trench 5a, whose length direction extends into the depth direction of the drawing plane, has the depth h_0 . It separates the left area, for instance used for the high potential P1, from the right area, used for instance for the low potential P2. The isolation area T, symbolizing the trench, creates a dielectric insulation, which will be described later on. Below the chip regions 6, 7 at the end of the active semiconductor layer 3 a horizontally buried insulating layer 2 is assumed, which is provided by the start wafer, that is, an SOI wafer that additionally comprises a carrier layer 1. The buried layer 2 has already partially opened by the trench, but will again be dielectrically closed by the following process steps in order to act as a barrier for the difference in potential P1-P2.

15 Insulating layers 4 are formed by thermal oxidation according to Figure 3b, thereby resulting in a reduced width b_1 of the trench 5a. The vertical portions of these insulating layers 4a and 4b are formed on the walls of the trench in an opposing relationship. Horizontal portions 4a' and 4b' belong to the insulating layers and are formed on the exposed active semiconductor layer 3 along with the vertical layer portions. A trench 5a' having a reduced width is obtained, which has an increased depth, since the horizontal portions 4a', 4b' provide, to some extent, for an additional vertical height at the top of the active semiconductor layer 3.

20 The two chip regions 6, 7 to be insulated remain unchanged throughout the entire sequence of Figures 3.

25 Next, a process step is performed to fill the trench 5a'. This fill process is performed such that at least the one isolation trench is filled with a fill material, wherein a deepest indentation of notch 5c of a fill material layer 5', 5" formed at the surface is located with its top surface above a level 4c that is defined by a planar surface formed by the

insulating layers 4 (the horizontal portions thereof). The notch is not depicted in a real manner and is not true to scale, but is a symbolic representation. The deepest level 5c thereof has height offset h6 with respect to the planar surface 4c that is used as a reference plane. The filling of the isolation trench with the fill material defines a first portion 5*, which is also referred to as a vertical fill material. Two horizontal fill layers having the same fill material are indicated as 5' and 5" that are located on respective opposing sides of the trench, that is, above the horizontal insulating layer 4a' at one side or above the horizontal insulating layer 4b' at the other side. At the trench 5* the horizontal fill layer has an indentation.

10 The thickness if the horizontal portion 5', 5" of the fill material layer 5 is indicated as h5 and is somewhat greater than the thickness of the insulating layers 4.

15 The filling of the trench with the vertical portion 5* of the fill material is thus performed "beyond the planar surface 4c", which means an application of the fill material. This information, i.e., the extension beyond or above the surface 4c, is defined by the surface or plane, which has the offset h5 in the height direction. This refers to Figure 3c. In an intermediate step with respect to Figure 3d that is not shown the horizontal portions 5', 5" of the fill material layer are planarized, that is, material is removed, such 20 that the insulating layers, i.e., their horizontal portions 4a', 4b', are again exposed. This is the first planarization.

25 Subsequently, a defined back-removal process, in particular in the form of a back etch process, is performed so as to obtain the trench structure according to Figure 3d. This removal of a vertical portion of the fill material 5* relates to a part of the fill material in the interior of the trench and extends to a defined depth h7. This depth extends below the previously indicated reference plane 4c, which is now defined by the exposed top surface of the horizontal portions of the insulating layer 4. The etch-back process is performed deeper than a second reference plane 4d, which is defined by the surface of 30 the active semiconductor layer 3.

35 A height level h8 is obtained in the trench 5a', which corresponds to the fill material, in particular to the polysilicon. The defined depth obtained by the etch-back process, wherein the measure of the etch-back is indicated as h7 and the measure of the remaining trench is indicated as h8, merely corresponds to a small part of the trench depth according to Figure 3d. It is etched down to only half of the trench depth or less, preferably to approximately $\frac{1}{4}$ of the trench depth or significantly less according to further embodiments.

A real ratio is shown in Figure 4.

Thereafter, the insulating layers 4 are further etched back, wherein here the horizontal insulating layers 4a', 4b' and a part of the vertical insulating layers 4a, 4b are involved. With this etch-back process a defined over-etch of the vertical fill layer 5' is achieved such that the three vertical layers 4a, 5* and 4b have substantially the same height level as shown in Figure 3e. This height level is obtained by the etch-back process using the measure h9 with respect to the surface 4d of the active semiconductor layer 3. The actual etch-back for the obtaining the result of Figure 3e relative to Figure 3d is greater, since the horizontal insulating layers 4b' and 4a' are also removed:

It is thus removed a part of the insulating layers and a part of the vertical fill layer in order to obtain and form a receiving portion that is located between the trench walls and is located more deeply than the surface of the active semiconductor layer 3. This layer is exposed according to Figure 3e.

The opening provided has a width b9 and a depth h9, the latter is referred to the surface 4d. The application of a cap layer 9 results in a filling of the this deeper lying volume and concurrently covers the plane 4d so that it extends above the level of the planar surface. The extension above or protrusion is to be understood in the vertical, upward direction, at the same time the cap layer extends, after forming the same on the surface 4d of the active semiconductor layer 3, in the downward direction to the substantially identical height level in the trench. The latter corresponds to the height level of the surface 4d minus h9.

This intermediate step is not shown. Illustrates is the result of the next intermediate step, in which a material removing planarization is performed, for instance by a chemical mechanical polishing process or by a resist planarization. The corresponding process result is shown in Figure 3f, wherein the described volume of Figure 3e is filled with a cap layer 9 that is indicated as F. The active semiconductor layer 3 is also exposed. The isolation trench cap 9 may thus be obtained without a mask. The cap ensures a suppression of a possible oxidation of the fill material 5*, may simultaneously provide lateral insulation and extends between the trench walls without an intermediate layer of any of the two vertical portions 4a, 4b of the insulating layer 4.

Not illustrated are several layers as a sequence of layers instead of the single layer 9 according to Figure 3f. In this case, individual layers may have specific characteristics in order to affect the expansion behaviour or the getter capability for ions.

5 If only one layer 9 is provided that forms a „cap“ of the trench, this layer may be made of silicon nitride. It is not oxygen permeable and is electrically sufficiently insulating.

10 The adjustment of fill material 5* and cap layer 9 provides for the avoidance of a bending of the semiconductor wafer during subsequent processes. The upper portion of the filled trench does not oxidise so that different coefficients of expansion may not occur. The adjustment of the vertical insulating layers, the fill layer and the cap is performed in tailored manner.

15 Despite the stability and process safety achieved a surface F is obtained that does not contain any steps. This especially holds true for the trench and the adjacent area.

20 It is not adverse when the fill material 5* is electrically conductive, since the dielectric insulating layers 4a, 4b are provided. It is also not a problem that this fill layer is oxidizable, since the cap layer 9 provides a barrier with respect to oxidation in subsequent high temperature processes.

25 With respect to the depth of the material removal it has been mentioned for the transition from Figure 3c to Figure 3d that the depth of the trench is not nearly reached and the removed portion having the depth h7 and h9 represents a small volume of the fill material 5*. This is a consequence of the very deep trench structure, which is designed for a high insulation capability and a relative thick active semiconductor layer. The depth of the trench and the width of the trench may be combined to an aspect ratio. This aspect ratio is higher than 10:1 (depth to width), preferably higher than 15:1. In other words, a deep narrow trench is meant, which is clearly demonstrated in Figure 4.

30 35 In a similar manner the depth of the second over-etch process has been selected to obtain Figure 3e. Also in this case the removal is not deeper than down to half of the trench depth at most, typically and preferably significantly less deep in order to not unduly increase the thickness of the cap layer. A preferred measure in this case is $\frac{1}{4}$ of the trench depth or significantly less, when the trench depth corresponds to a situation as illustrated in Figure 3e or Figure 4. The trench depth in Figure 3d is selected differently, since here only the horizontal insulating layers are provided, which may have

no undue affect with respect to their extension and which are illustrated in an exaggerated manner for the sake of clarity.

The thickness of the layer 9 may be less than 1 μm .

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reference signs

- 1: semiconductor wafer (substrate)
- 5 2: buried insulating layer, for instance SiO_2
- 3: active semiconductor layer(s) carrying devices
- 10 4: insulating layer, for instance SiO_2 (in the form of layer portions 4a, 4b)
- 5 5: fill layer, for instance polysilicon, possibly conductive
- 15 6: active silicon area at potential 1
- 7: active silicon area at potential 2
- 8: oxide layer (pad oxide)
- 9: cap of the insulating isolation trench, for example, Si_3N_4
- 20 F: surface (planar)